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Guest Editor
David Blockley, Emeritus Professor and Senior Research Fellow, University of Bristol, UK

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Editorial: Structural risk

D. Blockley PhD, DSc, FREng, FICE, FIStructE

A SPECIAL PUBLICATION OF THE INSTITUTION OF CIVIL ENGINEERS WITH THE INSTITUTION OF STRUCTURAL ENGINEERS

The purpose of this special issue is to present reviews of the latest research thinking about the risk, reliability and vulnerability of civil engineering structures. Some researchers argue that structural risk is a mature discipline. The personal view of the guest editor (and not necessarily of the guest contributors to this issue) is that, while it has made strong advances, much more development is required before it can smoothly be incorporated into practice. On the human scale, I estimate that it is about 16 years old: strong and growing up fast but still lacking maturity. All of the papers are aimed at nurturing that important development which will eventually ease the topic into mainstream practice. In that respect all of the papers are intended to be of interest to practitioners.

This issue has eight invited papers covering topics from the vulnerability of sensitive and historic structures in seismic zones to the risk issues behind the Eurocodes.

We start with the vulnerability of sensitive and historically important monumental structures. With its vast number of ancient churches, palaces and other antiquities, the problem is particularly acute in Italy. Theoretically simple risk registers are just inadequate. One reason is that the calculations do not prevent the ‘double counting’ of evidence. Bernardini and Lagomarsino describe some of the latest thinking in evaluating historic structures in seismic zones. A knowledge-based methodology based on the European macroseismic scale is used to develop criteria for the classification of buildings. It is based on evidence from differing sources varying from poor statistical data to detailed descriptions of single monuments. The authors use some of the latest interesting theoretical tools based on non-classical evidence theories such as fuzzy sets, random sets and imprecise probabilities, which avoid double counting. Vulnerability curves have been derived based on recent Italian earthquakes. The work shows that churches appear to be particularly vulnerable.

The effects of a relatively small explosion in a block of flats at Ronan Point in London in 1968 were disproportionate. The terrible tragedy of 9/11 and the collapse of the World Trade Center in New York have again exposed how theoreticians have neglected structural robustness. Agarwal and England review the literature. Structural engineering is mature, they say, but it is often difficult to foresee where damage might occur that results in consequences that are disproportionate to the degree of damage. A robust structure will be able to cope with unexpected demands. There is, as yet, no agreed definition of robustness and hence no satisfactory measure. The difficulty is that we are dealing with risks that contain low chance/high consequence events. They point out that, while most studies assume a model of the loading conditions, robustness is also importantly a property of the form or connectedness of the structure.

Faced with the challenges of climate change and the need for sustainable design, structural risk is especially important for developing countries. Sánchez-Silva and Rosowsky state that developing countries need infrastructure development that is environmentally sound, socially acceptable, economically justifiable and sustainable. Financial pressures make long-term planning difficult. A balance between protecting the physical environment and using resources effectively is required. Engineers need models that are able to use and process large amounts of disparate information. As developing countries adopt the safety standards of developed countries then resources are directed away from other needs. Safety needs to be managed in the total context of the needs of the country.

Ellingwood is a world leader in the development of structural reliability theory. He recognises the early resistance to probabilistic methods but says that methods have developed to such a point that they are being used in modern codified design such as Eurocodes. In his paper he is concerned with how we deal with unforeseen events outside the traditional design envelope. He argues that infrastructure performance-based engineering offers a new paradigm. The important idea is that structural engineers must look beyond minimum code requirements if they are to meet the challenges ahead. Risks of unexpected events cannot be avoided. Risk-informed performance-based engineering requires a continuing dialogue among the project team and stakeholders with clear audit trails for key decisions about risk and safety. Uncertainty analysis must be a central part of the decision model. Tradeoffs must be treated candidly with a transparent decision process.

Vrouwenvelder summarises the treatment of risk and reliability in structural Eurocodes. He discusses how the Eurocodes deal with decision making under uncertainty. The links between partial factors and the underlying theory are highlighted by distinguishing between probability based design and fully probabilistic methods. He regrets that the theory seems to be understood by only a handful of specialists. For some special structures, such as the Maeslandt storm surge barrier in the Netherlands, designers have to consult specialists in the handling of statistical data. He notes that the Eurocodes give a number of tools for dealing with accidental loads but that most failures in practice occur despite the application of the codes. The use of codes should be embedded in a careful strategy for managing risks as recognised in the Eurocode itself. Reliability calculations done for the sake of the record only are almost useless.

The issues mentioned by Ellingwood regarding the acceptability of structural reliability are faced head on by Nethercot in a personal contribution to the debate. He states that enthusiasts of the theory are found almost exclusively in the academic community whereas reaction in the structural engineering community is decidedly mixed. Enthusiasts see reliability theory as a key tool, whereas practitioners see it largely as an irrelevance. He asks if this difference matters and, if it does, can it be bridged? He recognises the theory as a structured way of thinking through the problem by helping to identify key influences and potential contradictions. He identifies part of the tension as arising from confusion between the scientific method and the practice of engineering. He also highlights the importance of low chance/high consequence events and the need for a better theoretical understanding of robustness. He concludes by saying that engineers justify their work by saying they have used best practice and that is underscored by the presence of reliability theory.

Three leading thinkers about the theory of structural risk—Brown, Elms and Melchers—take the debate a stage further. Their contribution is particularly important in the maturing process of the subject. They begin by pointing out that structures seldom fail, so it is reasonable to conclude that they are safe. The process of achieving safety and the process of assessing whether safety has actually been achieved are, however, very different issues. They discuss this through the four related topics of responsibility, failure, uncertainty and decision. They argue that recent codes have focussed only on one aspect of uncertainty, which they call technical uncertainty, with little attempt to address non-technical matters that have been shown to be the origins of most failures. They argue that the decision process is one of 'satisficing' rather than optimising with a process, which is less rational than is generally supposed and requires a broader outlook from structural engineers.

The final paper is by the guest editor Blockley and is an attempt to begin to show how the need for structural engineers to think more widely can be achieved. A key difficulty is how to manage in a formal way the integration of information and evidence from many disparate sources. The approach suggested is based on systems thinking. The first distinction is between the 'hard physical' systems of traditional engineering science and the 'soft people' systems of engineering management. They can be integrated by focussing on the processes, which represent how physical objects behave and what people do. Measures of evidence called 'Italian flags' to integrate disparate evidence are introduced. Previously they have only been used qualitatively. In the paper a new quantitative theory is introduced.

The emergent themes through all of the papers are

(*a*) the need to develop a much better theoretical understanding of robustness to deal with the risks of unexpected low chance/high consequence events
(*b*) the explicit recognition of incompleteness, that is our inability to predict the precise future state of a structure and the possibility of totally unforeseen events
(*c*) a consequent emphasis on the management of the risks to a structure all through its life cycle; a process in which prediction has a major role rather like the 'observational method' used in geotechnics
(*d*) the need to recognise the structure as part of a complex, 'softer', wider context which has yet to be considered theoretically in the way that can underpin the issues that practitioners are required to face
(*e*) a much wider debate and deeper understanding of the relationship between the scientific method and engineering practice which can facilitate the maturing process
(*f*) the development of techniques to allow for the formal integration of evidence from many disparate sources which will facilitate clear audit trails and transparency of decision making.

In the view of the guest editor (but again not necessarily the guest contributors) the 'systems thinking' approach (Ref. 1 of the paper by Blockley) has much to offer to the much needed maturing of structural risk and reliability theory into mainstream engineering practice. I hope this volume has helped to nudge this process a little further along.